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ON A POSSIBLE MECHANISM OF PARTICLE EJECTION FROM THE SUN

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The reality of existence of magnetohydrodynamic vortices (m.h.v.) generated in the Sun is established by direct measurements of magnetic fields in the sunspot region, having mainly a bipolar structure [1 - 3]. The last appears as a result of egress of toroidal magnetohydrodynamic vortices from interior to the surface of the Sun. (see ref. [2, 3]). It is natural to assume that the ejections taking place on the Sun have a magnetohydrodynamic nature. They are not related to spot field perturbations, but are the result of short-lived magnetohydrodynamic vortices, the development of which being as fast as that of flare and prominence-type ejections.

There are two types of possible m.h.v. : those with inner walls far apart, when $D/2d \gg 1$ (Fig. 1 a) and those with close inner walls,** when $D/2d \approx 1$. The first are characterized by quasiequilibrium and a

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* Ob odnom vozmozhnom mekhanizme vybrosov na Solntse.
** interlocked (?)

smooth coming to the surface, usually at great angles to the surface of the Sun. The second ones are essentially unequilibrated and are distorted, stretching along the axis z and increasing their inductance, as was shown by experiments with models (Fig.1). VOrtices must not necessarily originate in the interior of the Sun. Their occurrence is possible anywhere, whenever there appear regions with high current densities and increased magnetic pressure as a result of current filament whipping or of instabilities inherent to plasma columns (overbalance).

Experimental investigations of vortices of the second type and of plasma jets generated by them, provided corroboration of a series of their specific qualities, which can be summarized as follows:

1. The vortex structure of the type indicated in Fig. 1 , does not vary with the type of gas (air, hydrogen, argon), provided the discharge energy is sufficiently great. In weak vortices, the plasma coaxial disintegrates into a series of current filaments.

2. No effect of current in the discharge, varying from 10^3 to 10^6 a. on the structure of preliminary ionization and gas pressure in the 10^{-3} mm.Hg $\rightarrow$ 1 atmosphere range has been detected (density from 10^{-10} to 10^{-3} g/cm^3).

3. Aside from the field H_φ, induced by filament's longitudinal field. there is inside the plasma coaxial a field H_z, formed by the twisting into a spiral of the longitudinal current. At its exit into a medium with lesser density, the spiral's diam ter increases sharply.

4. The current filament plasma, compressed between the two crossed fields H_φ and H_z, is characterized by a high stability, whose limit has not been exceeded in the whole investigated time interval $(5 \cdot 10^{-6} \div 2 \cdot 10^{-4})$ sec. The jet's extension is not attended by its destruction, but by plasmoid separation, constituting independent m.h.v. of same structure and pursuing the same expansion, extension and division (partition) cycle.

5. The jet's longitudinal velocities exceed several $(3 \div 5)$ times the transverse velocities. As a result, the jet acquires a fountain-like shape. The absolute values of v_z oscillated in model experiments from $4 \cdot 10^5$ to $1.5 \cdot 10^7$ cm/sec, depending upon gas pressure and currents in the discharge.

6. The plasma "coaxial" and more particularly the current filament emit a continuous spectrum. Despite that the temperature of the outer plasma "coaxial" does not exceed 3 eV, and that of the current filament — 30 eV.

7. X-ray emission of $200 \div 250$ keV from the current filament is observed at a $10 \div 20$ kV potential difference on the jet bypass. The acceleration of electrons inducing X-radiation takes place at field H_z variations. This acceleration process is facilitated by the pushing out of matter from the inner jet cavity, particularly near the current filament, where plasma fluctuations are greater than anywhere else. According to optical and probe measurements their frequency is of the order of 1 mc/s.

8. The fountain-shaped jets easily penetrate the magnetic fields. Experience shows that a jet with a 3 — 10 ka current permeates the longitudinal field to 50 koe.

9. The jet's structure is quite steady relative to geometrical dimensions of the vortex, varying in model experiments by more than one order.

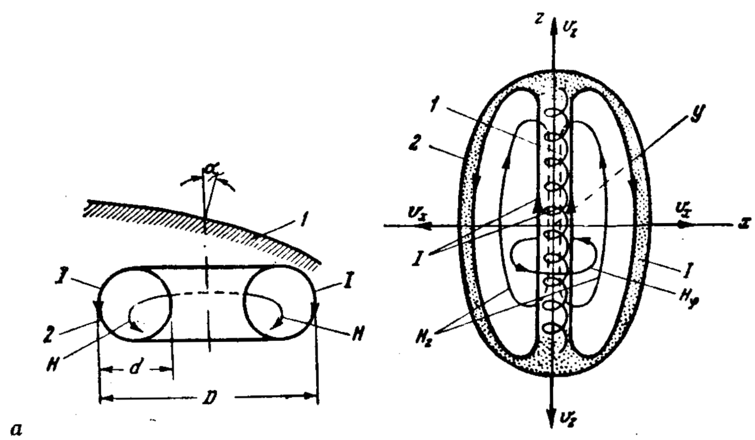

Fig. 1. a — emerging m.h.v.; 1 — surface if the Sun; 2 — toroidal current vortex; I — toroid's current; H_φ — magnetic field of the toroid; D and d — respectively the large and the small diameters of the toroid; b — structure of the m.h.v., stretching along the axis z ; 1- current filament; 2 — outer plasma "coaxial"; I — current flowing in the filament and in the plasma coaxial ; H_φ and H_z respectively the azimuthal and the longitudinal magnetic field.

This "uncriticalness" of the main m.h.v's properties to scale, time and current variations by $10^2 \div 10^3$ times provide the basis to assume that they are broadly distributed and appear everywhere so long as plasma currents exist. In particular they may play an essential role on the Sun, and not only in ejections, but also in the floccule emission, in chromospheric flares, in corona additional feeding, in turbulent exchange, etc... Obviously, the simple form of mhv referred to above does not exhaust the multiple shapes available in nature. Toroidal vortices may be bent, twisted and flattened, and in that case they create something of the a nature of a "paling" of jets, rather than a single jet. In the presence of an exterior magnetic field, jet interaction with magnetic fields occurs, particularly in the case of their slow ascent.

The m.h.v. scheme obviously calls for a further elaboration, processing and for making more precise its application to astrophysical problems. However, it is valid in the first approximation for the analysis of numerous processes. It may be seen by the example of ejections of the type of active and eruptive prominences and flares, that there is no serious contradictions between the m.h.v. scheme and the observation facts.

Let us begin with the exterior shape, though it does not constitute an argument for either hypothesis. According to a number of authors [7-10], all ejections, including the slow prominences and bulges, are extremely close in their shape to fountain-like jets. Photographs of limb flares [10] and of certain cases of eruptive prominences [7, 8] agree well with the above-described pattern of m.h.v., even without substantial corrections. We must however bear in mind that the emergence of m.h.v. on the surface of the Sun cannot escape being attended by the trapping and carrying of cold and dense solar plasma. The inner cavity of m.h.v., filled with rarefied gas, glows feebly, and that is why observers mostly fix the vortex-carried masses, rather than the vortex itself.

The schemes in Fig. 2, a, б, в, г, illustrate the phases of jet ascent, in the end passing to a chain of plasmoids, leaving the solar atmosphere and carrying along separate clusters of matter. It may also be applied to the whole class of the so-called "back-prominence", returning to the Sun after ascent.

Inside the vortex, power and magnetic pressure may oscillate within broad limits. That is why in some cases the disengagement of a m.h.v. from the cold mass of the prominence

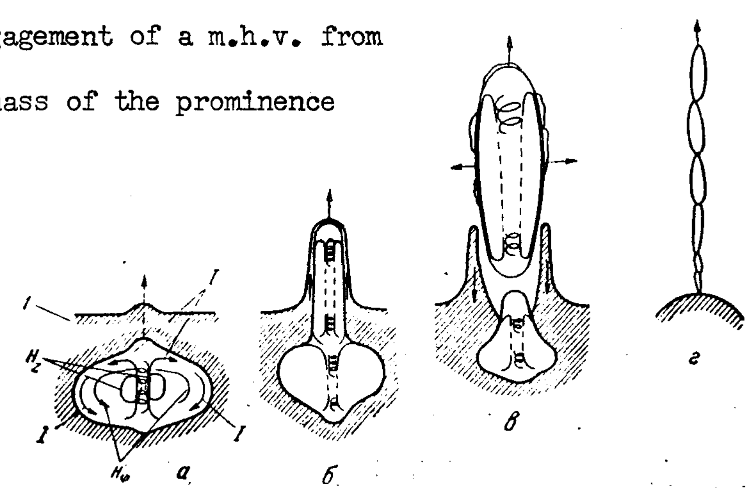

Fig.2.- Scheme of the emergence of a m.h.v. on the surface of the Sun. a — б — в — are sequences of the ascent; г — is the formation of a plasmoid chain. *1* — surface of the Sun; I, H_φ, H_z are respectively the current, the azimuthal and longitudinal field of the m.h.v.

may take place without a special disturbance, and in other cases — with the formation of shock waves and flares. This provides the possibility of explaining why flares are every time attended by prominences, but not every prominence gives way to a flare.

The capability inherent to many active prominences to recur time and again at the same sunspot place agrees well with the property of m.h.v. to disintegrate into separate plasmoids, property that may equally be revealed at the development of the plasma jet, as well as at vortex' emergence on the surface of the Sun (Fig.2b) As to slower prominences, their formation may be linked with the capture of exterior magnetic fields, hindering the interlocking of vortex' inner walls during the phase of its transition into a jet.

Magnetic Fields. Diffusion of the m.h.v.' H_z field into the outer region takes place with sufficiently great skin times [11] to exclude the possibility of their registration in short-lived prominences and flares. Direct measurements of m.h.v.' proper fields H_φ and H_z have a chance to succeed only when the vortex rises into the upper layers of solar atmosphere, upon liberation from the shielding sheath. No such measurements are available as yet. Thus only indirect conclusions are possible.

A. B. Severnyy and al [9, 10] have established two characteristics facts linked with flares: 1) Preferable, though by no means compulsory flare formation in neutral (zero) regions of the magnetic field and 2) redistribution and drop of magnetic field gradients after flares. Both these characteristics are explained within the framework of m.h.v. scheme: first of all by the fact that an ascending vortex encounters the smallest exterior magnetic field's counteraction in the neutral region, and secondly, by the disentanglement of a certain cavity occupied by the m.h.v., whose dimensions are apparently commensurate with those of the zone of magnetic fields' redistribution.

The velocities of ejections in the Sun are near those of laboratory plasma jets ($10^5 \div 5 \cdot 10^7$ cm/sec). Essentially, the m.h.v. scheme allows to explain the observed fact of plasma jet velocity accretion at ejections, at times tenfold ($10^7 \div 10^8$ cm/sec), for the acceleration of clusters, and particularly of frontal ones, continues in jets over all the time of existence of internal magnetic fields, gradually passing to the force-free structure. Even after the jet's disintegration into separate plasmoids the acceleration of frontal (leading) clusters will take place at the expense of the deceleration of the trailing m.h.v. The jet extension and plasma acceleration take place along the ejection trajectory.

Ejection Time. The length of jets in model experiments reached 10^2 cm, which incidentally did not constitute the limit. If we introduce the geometrical factor 10^7, then the time of solar ejections of $10^2 \div 10^4$ sec. duration agrees quite well with the measured (but not limit) time of plasma jet existence ($5 \cdot 10^{-6} \div 2 \cdot 10^{-4}$ sec).

Emissions. The accruing and pulsating character of flare glow my be linked with shock wave formation at m.h.v. emergence on the surface of the Sun. Inasmuch as the m.h.v. is compressed in the sub-photosphere region by exterior magnetic fields and inertia forces created by the carried masses, the gas kinetic and magnetic pressure in its cavity exceeds that of the surrounding medium. The appearance of separate plasmoids will be attended each time by new shock waves, causing light pulsation.

Spectra of prominences and flares do not provide any basis to assume the presence within them of superhigh temperatures, which corresponds entirely to plasma jet properties. The correlation between them may even be extended further as regards X-radiation, which according to direct measurement data [12] has in prominences and flares a hardness of hundreds kiloelectronvolts. The appearance of such high-energy electrons is difficult to explain by anything but the accelerating processes similar to those observed by us in plasma jets.

The X-ray radiation lag by minutes and tens of minutes relative to optical maximum, inherent to flares, stems from shock-wave processes taking place at different times and from most significant magnetic field variations in the inner cavity of the jet.

No sufficient data are available as yet for conclusions as to the maximum-attainable ion and proton energies in such a peculiar accelerator as the flying magnetohydrodynamic vortex is. However, the model experiments, where energies of hundreds keV have been reached, point to the possibility of generating in it of even relativistic particles.

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****** THE END ******

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